Indian Journal of Technology
Vol. 24, July 1986, pp. 440-446

Metal Finishing Challenges in the Fabrication of Radio Telescopes*

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Received 15 *April* 1986

The Raman Research Institute, Bangalore, has set up two radio telescopes (10.4 m and 1.5 m) for millimeter wave radio astronomy. Fabrication of these telescopes posed several challenges in metal finishing. Developing a coating for improving the wear resistance of the cutter used for *dry* machining of aluminium honeycomb, electroforming of corrugated horn with integral flange and circular-to-rectangular transition piece, and copper plating the 1 5 m FRP dish are some of the interesting problems that arose during the fabrication. The solutions developed for these problems are described here

A radio telescope is used to resolve a radio source of galactic or extragalactic origin and to study its spectrum and associated characteristics. Examining the radio source for emission in the millimeter wave (MMW) region of the spectrum gives information on various molecular species (e.g., combination of hydrogen, carbon, nitrogen, oxygen and silicon atoms) generally found in dense molecular clouds in our galaxy where star formation is thought to be taking place. Therefore, these studies are likely to throw light on the nature and mechanism of star formation.

The resolving power of the telescope is proportional to λ/D where λ is the wave length of the operating radiation and D is the diameter of the primary reflector or parabolic dish. Hence the need for large sized telescope operating at small λ or high frequency. The accuracy of the parabolic dish limits the highest frequency of operation.

The Raman Research Institute, Bangalore, has fabricated two radio telescopes for millimeter wave (about 100 GHz) astronomy, one of 10.4 m diameter and another of 1.5 m diameter. The accuracy of the parabolic dish in both the cases is better than $\pm 50\,\mu$m **(RMS).**

Fabrication of these telescopes posed several challenging metal finishing problems. A few of the important problems and their solutions are described in this communication.

Metal Finishing Problems Associated with the Fabrication of the 10.4 m Telescope

This telescope is a Cassegrain type with a primary parabolic reflector (10.4 m dia) and a secondary sub-reflector of hyperbolic shape to focus the signals, collected by the primary reflector, on to a cooled high sensitive receiver. At the inlet of the receiver, a corrugated horn acts as a collector and feeds the incoming high frequency signals to the front end where they are down converted to an intermediate frequency (IF) in a mixer. The IF signal is further amplified and converted to a frequency band, from which the required information is derived.

The technique used for the fabrication of the telescope is similar to that of Leighton[1] and is briefly described below.

The parabolic reflector is fabricated from hexagonal aluminum honeycomb sandwich panels. These panels are assembled on a back-up structure which is a network of struts held at suitable points by pin-joints. The top surface of the honeycomb is machined after assembly, to the required parabola by mounting the assembly on an aerostatic bearing. The rotary cutter is made to move on a guide rail [finished accurately (better than $\pm 30\,\mu$m) to the required parabola]. After the top surface of the panels was machined aluminum skins were vacuum bonded. The sandwich panels thus fabricated, are assembled on to the back up structure, which is driven by a drive unit. Fig. 1 shows a view of the 10.4 m radio telescope fabricated and erected at **RRI,** Bangalore.

It is needless to point out that machining of honeycomb panels is a vital operation in the fabrication. The machining should be burr free and the walls of the honeycomb should not tear even partially. The total surface area (geometric) of the parabola is 80 m^2. The HC HC cutter used for machining the surface used to lose its sharpness after machining an area of about 8 m^2. Therefore, the machining was not free from burrs

*Dedicated to Professor K S G Doss on his eightieth birthday.

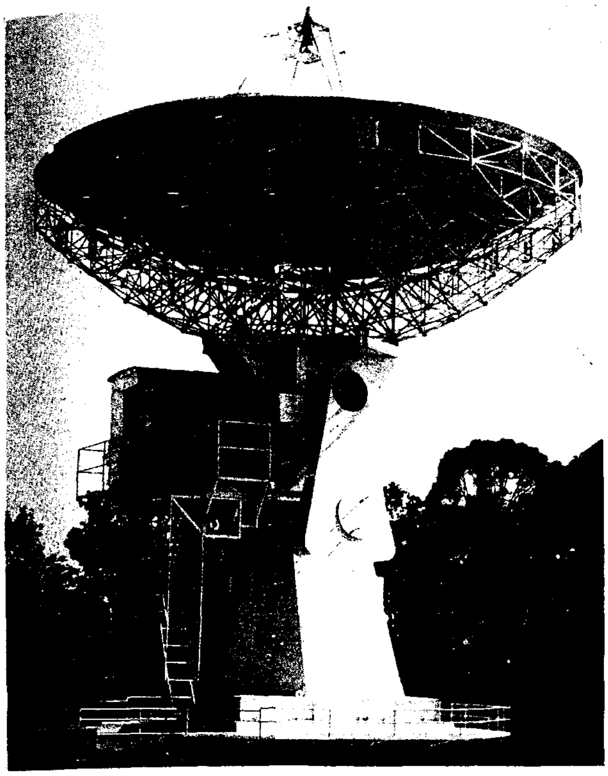

Fig. 1 — A view of the 10.4 m millimeter wave radio telescope set up at the Raman Research Institute. Bangalore

and the honeycomb walls got nicked and torn. The sharpness of the cutter became so poor that machining could not be carried out beyond $10 m^2$. An elementary solution to this difficulty would be to regrind the cutter after machining an area of $8 m^2$. This approach was not useful because, once the cutter is removed and refixed, the alignment error was found to be $\pm$ 100 pm. It is needless to point out that when the alignment error is $\pm$ 100 μm, the surface can not be machined to an accuracy of better than $\pm$ 50 pm.

The problem of machining aluminum honeycomb is the severe wear of the cutter caused by the adhesion of aluminum and the impact experienced by the cutter due to machining a cellular structure. To make the surface noncellular, filling the cells in honeycomb before machining is one of the recommended practices. For filling, frozen water[2], paraffin wax[3] and polyethylene glycol[4] (m.p., 71°C-82°C) have been used. Once the honeycomb is filled then, the filling material itself can act as lubricant.

This approach was not practical in the case of machining the primary reflector of the telescope because of the following reasons:

Filiing the cells with 'bees wax was tried. This reduced wear on the cutter, but had to be given up because it was difficult to clean the honeycomb after machining. It is essential that the honeycomb must be clean for ensuring proper bonding.

Fig. 2 — Coated HC HC cutter machining honeycomb panel

Filling with frozen water was not practical because of the need for refrigerating the large dish.

We did not use polyethylene glycol, though attractive, because it would have cost us Rs 2 million for filling the dish with it. Besides it increased the weight of the dish to about 15,000 kg which was beyond the designed load bearing capacity of the machining assembly.

For the reasons mentioned above we had to resort to dry machining of the honeycomb. For this purpose we had to improve the wear resistance of the cutter so that its sharpness would last for machining at least $80 m^2$ of honeycomb surface. Hard chromium was not satisfactory. For this purpose we developed a special composit coating based on boride which was applied by a chemical process (A patent for this process has been applied).

This coated cutter was able to machine about $500 m^2$ of honeycomb which is more than enough for machining the dish. With this coated cutter the machining of the dish was completed. The accuracy obtained **was $\pm$ 40 μm (RMS).** Fig. 2 shows a honeycomb panel being cut.

Treatment for the dish to increase diffuse reflectance — The surface of the primary reflector should not focus the ultraviolet and visible radiation. For instance, if the telescope is pointed to the sun, then about **80** kW of energy would be at the focus if the dish acted as **a** mirror for the visible radiation, because the solar energy is approximately $1 kW/m^2$. Therefore the surface of the dish is to be given a treatment such that the surface becomes a diffuse reflector for radiation of wave length less than 2 μm but is a good mirror for mm waves. For this purpose we tried a chetnical roughening method. The surface was first etched with 10% sodium hydroxide followed by 10% ammonium bifluoride. The duration of etching was about 3 min for each etchant. This treatment produced a surface with a roughness of 1.5-2 μm (Ra). The diffuse reflectance of this etched surface was 70% ($\lambda = 0.2$ - 2 μm). The surface absorption was about 15% and the specular reflectance was 15%. With this treatment it was found that the temperature at the focus was about 50°C higher than the ambient which was acceptable. This treatment proved to be very efficient in preventing the solar radiation from heating the secondary reflector at the beginning. However, the efficiency of this coating in diffusing the solar radiation has decreased significantly after a year's experience.

Secondary reflector— For the initial experiment, the secondary reflector was made of fibre reinforced plastic. This had to be metallized in order to provide surface conductivity. Metallization was done by depositing electroless copper (thickness 1 pm) followed by electrodeposited copper (thickness about 15 pm). To restrict the metallization only to the reflecting surface, the reflector was floated on the bath with the reflecting face in contact with solution. The procedure was the same as that employed for metallizing the 1.5 m dish which is described later.

Electroforming of corrugated horn— Corrugated horns are used in radio telescopes as feeds for reflector antennas (the parabolic dish described above). Horns with inside corrugations have high efficiency and low spillover a: the operating frequency. A typical horn required for the RRI radio telescope is shown schematically in Fig.3. For purpose of clarity the flange has been omitted. The groove depth and width are not the same throughout the length of the horn. Near the throat section, the groove depth is approximately half the wavelength which gradually tapers off to quarter wavelength. Besides the problem of deep rectangular grooves, this horn has a flange (not shown in Fig.3) which must be perpendicular to the axis (within 0.1°). An additional requirement is that a circular-to-rectangular transition should be integral with the horn.

Even though machining and casting techniques have been used for fabrication of corrugated horns[5,6], these techniques are no! useful for making horns used at frequencies above 20 GHz.

Problems associated with electroforming of corrugated horn— The primary requirement of a corrugated horn is uniformity of the corrugated profile over the entire length. Though it is easy to machine out of aluminum a mandrel with inverse groove pattern on the external surface, it is difficult to ensure uniform deposition because of the problem of poor throwing power of electroforming baths.

At a right angled inner corner current density tends to zero (due to field effect). Consequently, there is no deposit at the corner when plated from simple acid copper sulphate bath. This results in the so-called corner weakness. High current density at the outer right angled edge leads to heavier build up. As a result of these two effects the deposit distribution is similar to the one shown in Fig.4. Hairline crack formation at the corner and edge build-up can be avoided by making use of suitable additives to the electroplating bath. Addition agents correct the corner defects by improving macro and micro throwing power. However, one should be cautious in using this method, especially in electroforming (which produces a free standing structure), because, such additives can lead to stressed deposits with poor mechanical strength.

The most commonly employed solution for making horns with varying groove depths appears to be the use of a hybrid technique involving electroforming and machining. Two such procedures described in the literature are outlined below.

Dragone[7] has described such a technique for making a corrugated horn designed for 100 GHz. The mandrel is made up of brass discs (to form the ridges) and aluminium spacers (to form grooves). Brass and

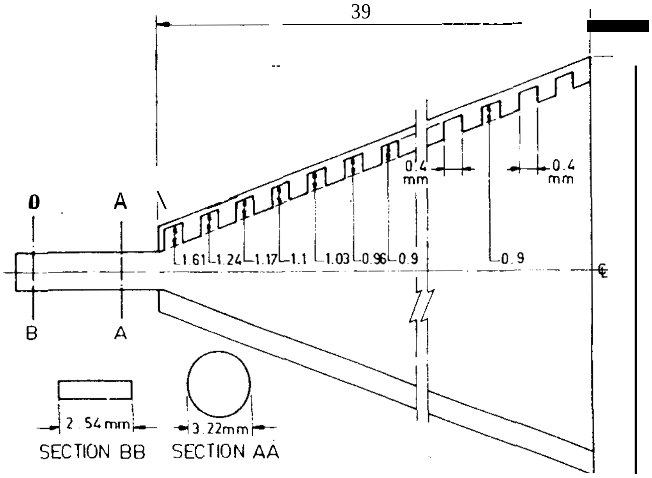

Fig. 3— Schematic diagram of the corrugated horn designed by the Raman Research Institute for their 10.4 m and 1.5 m telescopes

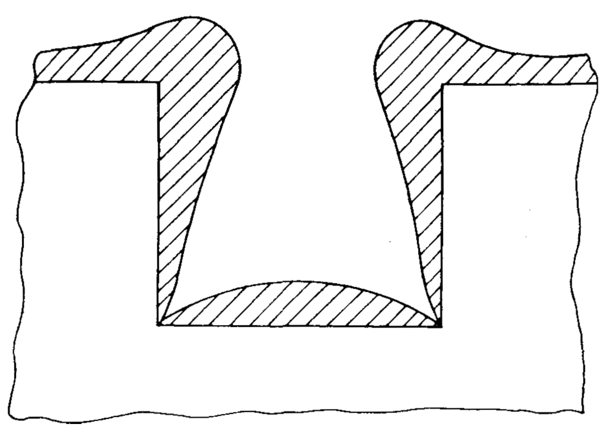

Fig. 4— Cross-section of a groove plated from an acid copper bath showing the metal distribution and corner defect

aluminium discs are assembled alternatively and held together in a jig. The external surface is machined to form a cone. Copper is then electroplated on to the external surface to a suitable thickness. The external surface is again remachined. Using the external surface as a reference the assembly is bored to develop a hollow cone. On the inner surface of the cone, brass and aluminium rings will be seen alternately. The aluminium is dissolved in sodium hydroxide solution to generate a corrugated horn. The disadvantage of this method is that good contact around the base of the slot is difficult to guarantee. A poor contact can be highly damaging to the operation of the horn.

Von Otto Tuscher and Richard Suchentrunk[8] have described an interesting procedure for making corrugated horn by electroforming/machining. An aluminium mandrel with inverse groove pattern and flanged tail end is used as the substrate. On to this mandrel nickel is deposited by electroless or electroplating method to a thickness of 0.12 mm. The grooves are then tilled with conducting wax and the external surface is machined smooth. It is then plated with 0.3 mm thick nickel layer. After this plating slits are made by machining away the conducting wax which is used to fill the groove. Finally, the aluminium core is dissolved in sodium hydroxide to give the horn. It is obvious that this method is time consuming, laborious and requires precision machining of inner grooves. It is worth mentioning that this technique would be subject to all the limitations of the machining technique.

John Lichtenberger describes in a National Radio Astronomy Observatory report’ a procedure for electroforming corrugated horns. He makes use of a proprietary acid copper plating bath which uses a patented addition agent to produce bright levelled copper plate. He points out that a direct electroforming can only be used if the depth of the groove is smaller than its width. If the depth is more than the width, as is the case in the throat section of the corrugated horn, it is not possible to electroform the horn in a direct fashion. In such a case, he recommends that copper inserts must be machined to fit these deep grooves and grown into the electroform.

To the best knowledge of the authors no method of making corrugated horns (with variable groove depth) entirely by electroforming has been described in the literature. The procedure adopted by us in achieving this is outlined below.

It has been pointed out earlier that the corner defect arises from the current density tending to be zero at an inner right angled corner. If the surface of the mandrel has an appreciable surface resistance, then the current density distribution would be decided by the resistance. If the surface resistance is uniformly high over the entire profile of the groove, then the deposit must be uniform.

In principle, it is possible to form a poorly conducting oxide film on aluminium. If the plating is carried out over this oxide film, the deposition is expected to be uniform.

This idea was tested by forming a chemical conversion coating over aluminium with the following solution:

Sod·um hydroxide	:	20 gpl
Sodium chromate	:	50 gpl
Temperature	:	30°C
Time	:	2 min

Over this coating, copper was directly plated from a standard acid copper plating bath using phosphorous depolarized copper anodes at a current density of $1 A/dm^2$. The aluminium mandrel was dissolved in sodium hydroxide based bath at 90°C.

A cross-section of the corrugated horn electroformed by this procedure is shown in Fig.5. It is seen that the deposit thickness is uniform over the entire profile.

Forming an integral flange also posed problems. Again, there was poor deposition at the right angled corner of the flange. It also took a considerable amount of time to form a flange of adequate thickness.

These problems were solved by attaching a machined copper flange by electroforming to the electroformed horn. To achieve this the following procedure was used.

While machining the mandrel a tail of adequate length was machined to have a rectangular cross-section at the end. Over this mandrel electroforming was done using the procedure described above. After growing some thickness, the forming operation was stopped and the flange was friction fitted to the mandrel and the forming continued. This helped to bond the flange to the electroform. To avoid the

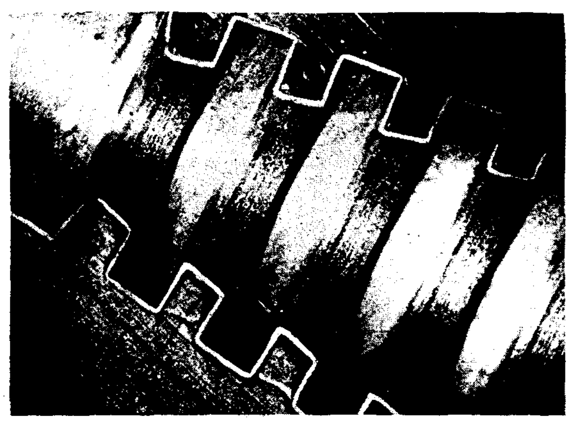

Fig. 5— Cross-section of the electroformed horn; uniformity of deposit thickness over the entire profile is seen

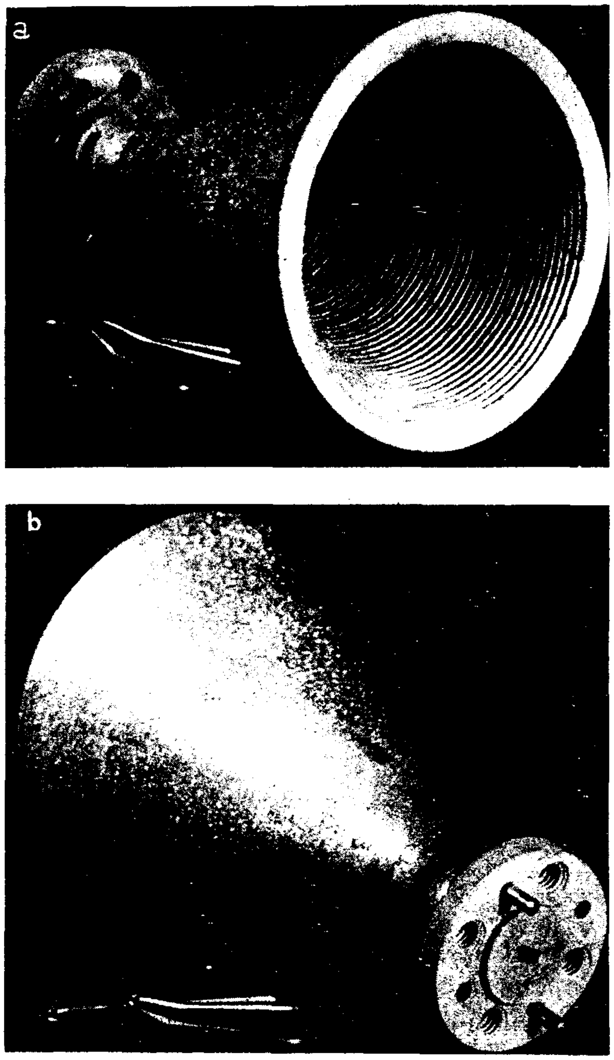

Fig. 6— Corrugated hoin electroformed by the procedure described in this paper: (a) View showing the transverse grooves on the inner surface; and (b) View showing the integral flange and the rectangular opening in it

problem of corner defect at the right angled edge of the flange appropriate fillet radius was provided for the flange. It is important to join the flange after depositing a definite thickness over the mandrel. If this is not done, there will be a discontinuity at the flange - throat interphase, which will impair the performance of the horn.

Photographs of a typical corrugated horn electroformed by the above procedure are shown in Fig.6(a) and 6(b).

This performance of several horns electroformed by the above method was evaluated at the frequency range 85-115 GHz (for which it was designed) and it was found to be excellent''. After ensuring the performance, the horn is being used in the receiver section of the telescope.

Goldplating of the interior of the stainless steel wave guide— Rectangular wave guides of dimensions 1.25 mm x 2.5 mm x 150 mm long made of stainless steel is used in the receiver system for studies at 85-115 GHz range. This wave guide is used inside a chamber cooled by liquid helium. Cone end of the wave guide is at room temperature. Stainless steel is chosen because of its poor thermal conductivity. However, to have high efficiency at the frequency range of its use, the inside surface must have excellent electrical conductivity, Hence it is required to coat gold to a thickness of at least 2 μm inside the wave guide. Plating the interior of such a wave guide naturally poses the problem of plating the interior of a narrow bore. This problem was solved by the following way:

A suitable jig out of perspex was made for holding the wave guide. Two perspcx plates with a channel having the same width as that of the wave guide was used to hold the job. One of the perspex plates was provided with screws on either end which were used to hold the platinum wire anode at the centre of the wave guide. Since the bore of the wave guide is narrow the plating was carried out with ultrasonic agitation to prevent depletion of the bath which would result in poor quality deposit.

To secure adhesion of gold on to SS, which is a difficult to plate substrate, Wood's nickel strike was given to the SS wave guide. Electroplating of gold was done in a buffered phosphate gold plating bath.

Every five minutes the job is raised and dipped again to ensure that the gold solution in the interior of the wave guide is replenished. Measurement of resistivity established the uniformity of deposit throughout the length of the wave guide.

Metal Finishing Problems Associated with the Fabrication of 1.5 m Telescope

This telescope is also a Cassegrain type. The primary reflector is a parabolic metallized FRP dish of 1.5 m diameter. It is mounted on an aerostatic bearing to facilitate tracking. The signal collected by the dish is sent to the receiver by plane mirrors. Fabrication of this telescope posed two additional problems, viz., making metallic mirrors and metallizing the FRP primary reflector.

Fabrication of metallic mirrors— Metallic mirrors are being used in the 1.5 m radio telescope subsystem to reflect the mm wave signals focussed by the secondary to a convenient point for further processing. The mirrors 180 mm x 220 mm x 10 mm should have a surface finish of better than 0.1 μm in the central region (20 mm dia) for alignment using light and surface accuracy of $\pm$ 10 μm in the rest of the area for use at the frequency range of 85-115 GHz. The surface of the mirrors should also have good conductivity and they must be light. Aluminium is a good choice from the point of view of its light weight. Due to its softness aluminium cannot be ground to achieve the desired finish. Hence aluminium must be plated with nickel which is a hard material and easy to polish. However, because of its natural oxide film on the surface, adhesion of nickel on aluminium is a problem. To overcome this a suitable surface treatment is given on aluminium and nickel is plated. This is mechanically polished with cerium oxide to achieve the desired surface finish, and to improve reflectivity of the surface aluminium is coated on the nickel surtace by vacuum evaporation. Four such mirrors were fabricated by this method and all are currently being used in the 1.5 m radio telescope assembly.

Metallization of **1.5** *m FRP dish* – The skin depth for copper at 1 mm is about 0.2 μm. Therefore, a deposit of copper of thickness about 20 μm would be more than adequate for providing the surface conductivity. Since a large enough vacuum evaporation facility for handling this job was not available and because in metal spraying we cannot get the type of surface finish needed, it was decided to metallize this dish by plating. To make the surface conducting for plating electroless deposition of copper was chosen.

For plating on plastics pretreatment is very important. We used the compositions sold by Shipley Company Inc., **USA''.**

The following steps are followed for pretreatment and activation of the surface for the electroless plating of copper.

1. The surface of the dish is conditioned by using a solvent mixture (cleaner **PM-900).** This prepares the surface for effective etching. Rinsed and dried.
2. The surface is micro-etched by using a chromic acid based bath (Circuposit 1200) for the purpose of ensuring good adhesion between copper and epoxy surface, and rinsed.
3. The excess of residual chromium trapped within the pores of the etched epoxy is removed by treatment with neutraliser **PM-950** and rinsed.
4. Since the surface treatment **(3)** requires an alkaline bath, it is neutralised by **HCI** dip and rinsed.
5. The surface is catalysed by catalyst 9F based on palladous chloride and hydrochloric acid.
6. Surface is treated with accelerator 19 to protect electroless copper bath from contamination and rinsed.
7. Electroless copper is plated from Cuposit copper mix 3280,

The dish has a surface area of approximately **3** m^2 and diameter of 1.5 m. If the dish is to be treated by total immersion, then the back surface of the dish must be protected from coating. To immerse the entire dish we would need a volume of nearly 500 litres. If we use the dish itself as a container by plugging the hole at the bottom then the volume needed will be about 200 litres. Since a large number of steps are involved, the metallization will be expensive if 200 litres of each solution is used. The fact that only one dish is needed makes the process all the more expensive.

With a view to reducing the cost we thought of spraying the chemicals on to the surface for the steps 1 to 6. **As** far as electroless deposition is concerned, there is a relation between surface area coated and the volume of the bath. This loading factor needed a volume of 200 litres for the job. We discussed with Shipley to find out whether we could spray the chemical instead of dipping the workpiece. They told us that they did not have experience on this aspect. However, they felt that spraying might not yield satisfactory results. They confirmed that 200 litres would be enough for electroless plating.

Since we could not find any serious mistake in treating the surface by spraying we decided to adopt this procedure. For this purpose a special arrangement was made and is described below:

A PVC tube of about 10 mm diameter was bent circularly to run along the edge of the parabolic dish. The tube had perforation throughout its length to spray the solutions uniformily on to the dish. The parabolic dish was kept over an air bearing base so that it can be rotated freely. The solution sprayed on to the dish was collected in a sump through a central hole of the parabolic dish. The collected solution was pumped back through the **PVC** tubes and sprayed on to the dish. This arrangement minimised the volume of the solution needed at each stage of the surface pretreatment by a factor of ten. Fig.7 shows a view of the set-up used for spraying.

Electroless copper plating was done by plugging the central hole and filling the solution in the dish itself, that is the dish acts as a container. **A** thin sheet of **PVC** was bent and fixed round the dish to form a rim over the dish. This helped deposition up to the top.

After electroless plating the solution was drained and the dish was rinsed and dried. After 12 h copper was electroplated from standard acid copper bath. For electroplating, the dish itself was used as the container.

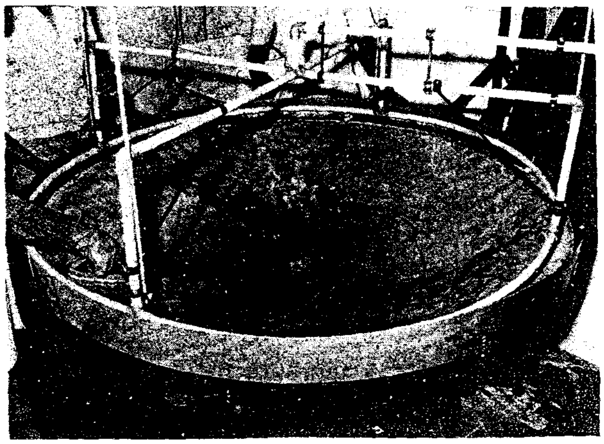

Fig. 7 — Set-up for spraying the pretreatment chemicals

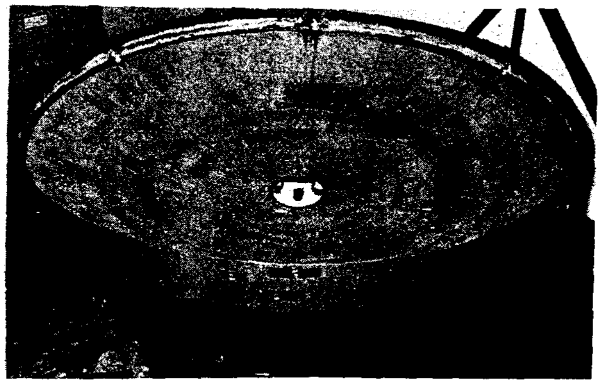

Fig. 8— A view of the 1.5 m parabolic dish after copper plating

Twelve strips of copper plate fixed to a central circular copper disc served as the anode. The strips which were radial were bent to conform to the shape of the cathode. The central disc in the anode was stopped off to ensure uniform current distribution. Electrical connection to the cathode was given at 24 places to distribute the current uniformly. Screws attached to the PVC rim acted as cathode leads. To prevent damage of the thin electroless copper deposit, a copper foil was interposed between the screw and the deposit. The plating was started with a current density of 0.5 mA/cm^2 and after 1 h slowly raised to 1 mA/cm^2 which was the plating current density. The plating was carried out for about 20 h to get a thickness of about 20 μm. After plating, the dish was rinsed and dried. Fig.8 shows a view of the dish after plating. This dish is used in the 1.5 m telescope and is functioning very well.

Acknowledgement

We thank Prof. N V G Sharma, Mr M O Modgekar and Mr R Nandakumar for their helpful suggestions. We thank Mr S Gopalan and Mr Charles-Paul for their help in coating the 1.5 m dish. Our grateful thanks are also due to Prof. V Radhakrishnan for the stimulating discussions.

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